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Mechanical Properties and Microstructural Characterization of Particulate Reinforced Diboride Composites for High Temperature Leading Edge Applications

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Abstract: Previous work on refractory diboride composites has shown that these systems have the potential for use in high temperature leading edge applications for reusable reentry vehicles. Experiments in reentry environments have shown that these materials have multiple use temperatures greater than 1900 C. The work to be discussed focuses on three compositions: HfB2/SiC, ZrB2/SiC, and ZrB2/C/SiC. These composites have been hot pressed and their mechanical properties measured at room and elevated temperatures. Extensive microstructural characterization has been conducted on polished cross sections and the fracture surfaces have been examined to determine their failure origins.

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Mechanical Properties and Microstructural Characterization of Particulate Reinforced Diboride Composites for High Temperature Leading Edge Applications

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Outline

- Thermal Protection Materials and Systems
  - Background
  - Blunt Leading Edges
  - Sharp Leading Edges
    - Safety Benefits
    - UHTC Materials
  - Summary

Trans-atmospheric* Vehicles

System	Function
1) Propulsion	Provide Delta V
2) Structure	Provide Form & Connectivity
3) GN&C	Provide Flight Control
4) *Thermal Protection (TPS)*	*Provide Thermal Isolation***

- **Systems analyses have shown that TPS is the <u>second</u> most important vehicle system (behind propulsion) relative to life cycle cost and risk**

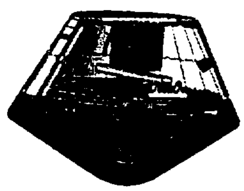
*- Reusable Launch Vehicles and Planetary Entry Spacecraft
**- From the hypersonic shock layer

Future Vehicle TPS : Minimize Life Cycle Cost; Maximize Safety

Minimum Vehicle Life Cycle Costs:

- Minimum weight & maximum performance (acreage)
  - Very light-weight, very high temperature capability, very efficient insulators
- Very high thermal gradient materials (leading edges)
- Low manufacturing costs
  - Billet processing, novel fabrication concepts
- Low maintenance
  - Robust for induced and natural environments, fail safe, enable automated inspection

Spacecraft



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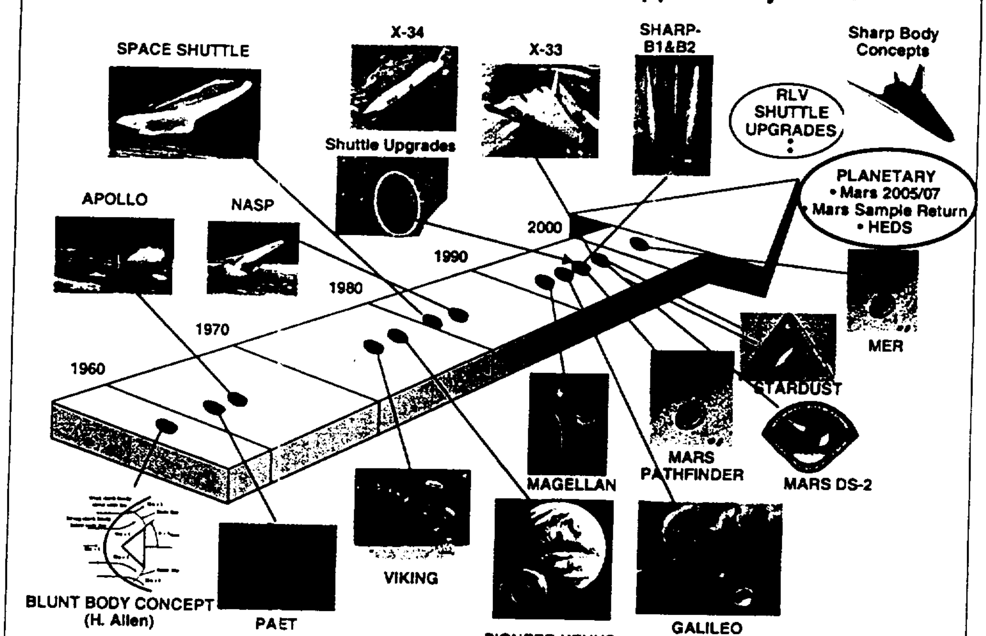
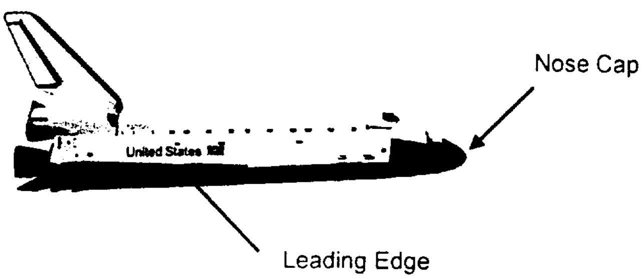
NASA Entry Vehicles and Missions Supported by Ames



RCC is Used on the Shuttle's Nose Cap, and Leading Edges

Reinforced Carbon Carbon (RCC)
- All carbon composite
  - Graphite fabric impregnated with phenolic resin
- Outer surface converted to SiC for oxidation resistance
- T ~ 1650°C



TPS

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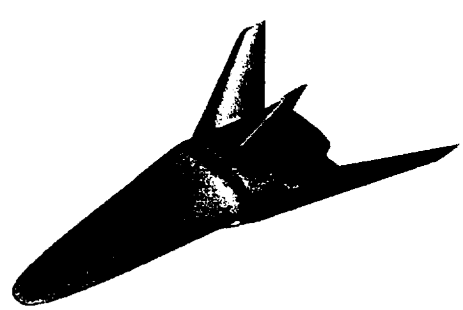
Sharp Leading Edges Provide Increased Safety and Performance

- Reduce propulsion requirements by decreasing drag
- Increase maneuverability
- Increase time during ascent for safe abort to ground
- Increase out-of-orbit cross range which enhances safety by increasing the number of potential landing sites



TPS

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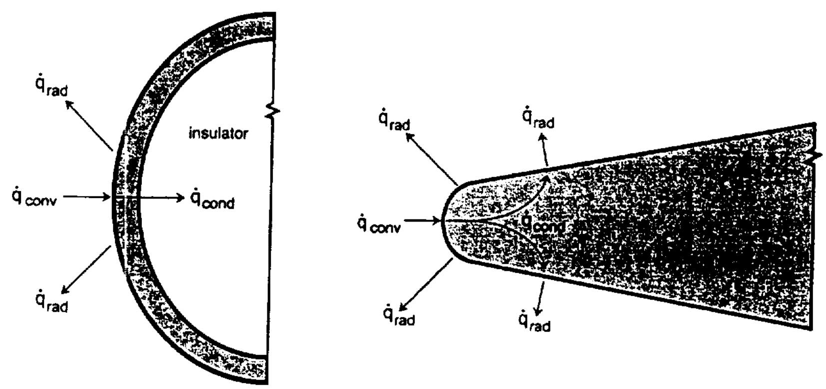
Surface Energy Balance



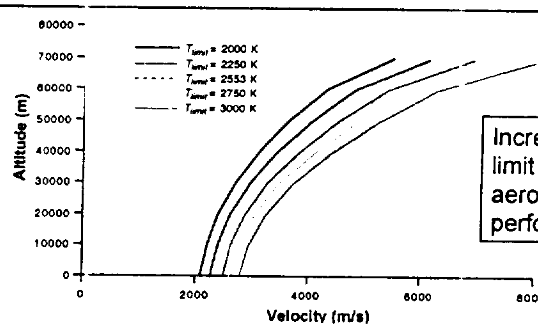
Blunt Nose

$$\dot{q}_{conv} \approx \dot{q}_{rad}$$

Sharp Nose

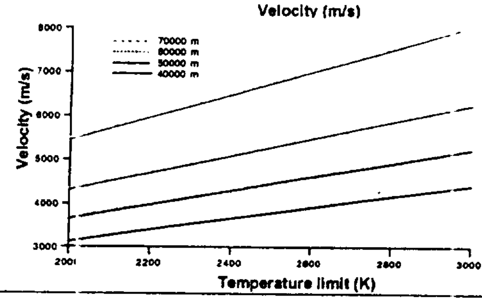
$$\dot{q}_{conv} = \dot{q}_{rad} + \dot{q}_{cond}$$

Temperature Limit Sensitivity

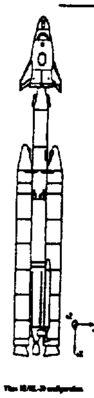


Increasing temperature limit greatly improves aerothermal performance constraint

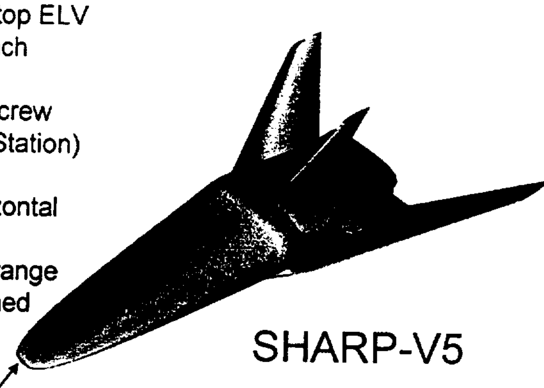
$R_n = 0.005$ m
$\theta_c = 15°$



Crew Transfer Vehicle Mission



- vertical launch atop ELV (Expendable Launch Vehicle)
- 8 passengers, 2 crew
- ISS (Int'l Space Station) rendezvous
- unpowered, horizontal landing
- maximum cross-range trajectories examined

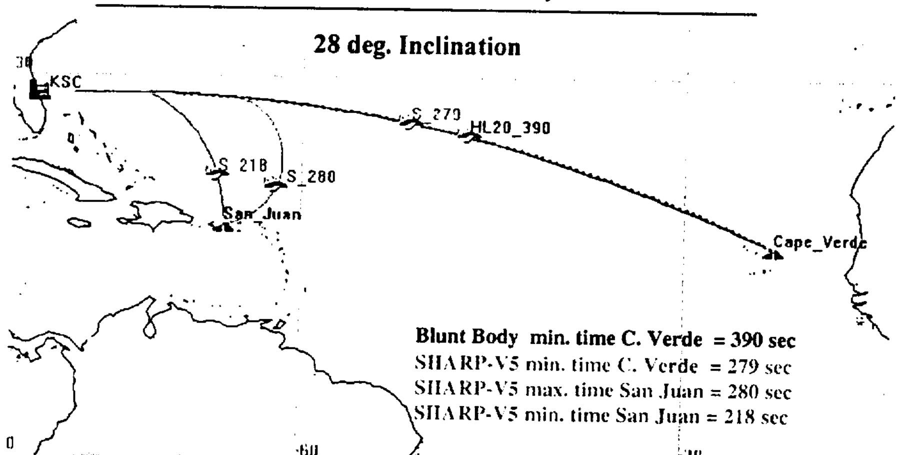


SHARP-V5

Ultra-High Temperature Ceramic (UHTC) Leading Edge

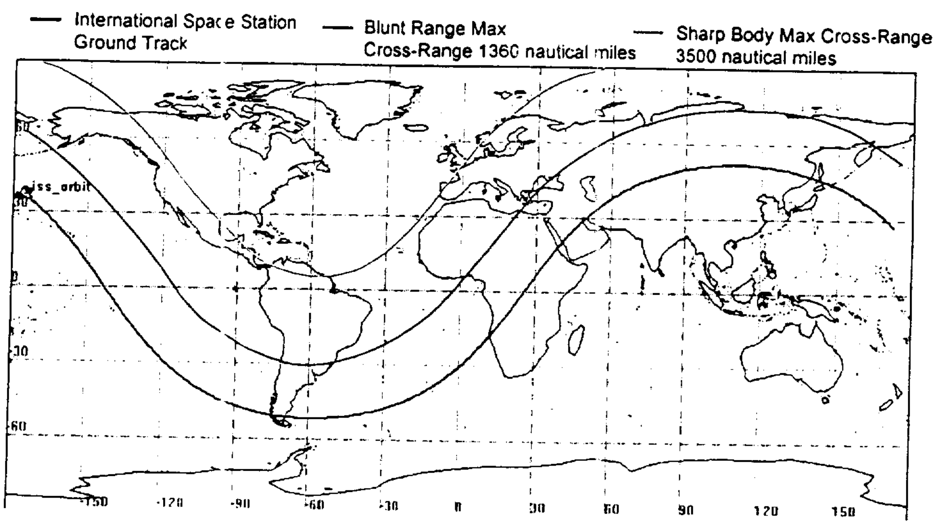
Potential Benefit - Impact On Crew Safety

28 deg. Inclination



Results of the SHARP CTV study show the potential of minimizing the need to abort into the ocean by increasing the capability of landing on a runway in the event of a failure during launch. 390 - 218 = 172 seconds improvement.

ISS Ground Track vs. Cross Range

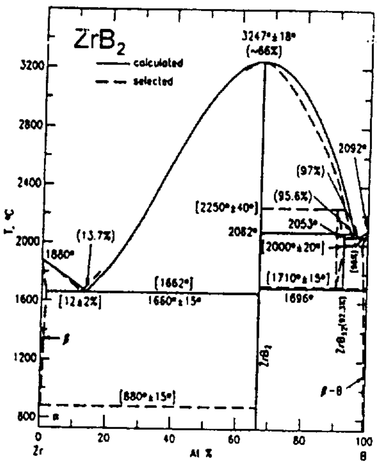


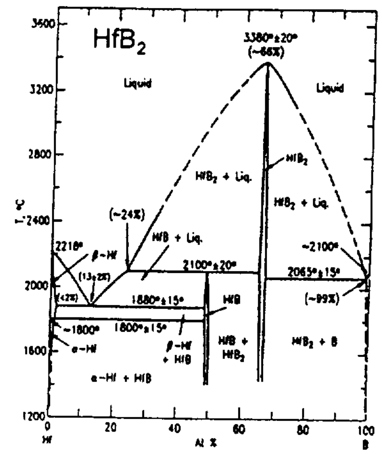
Interest in UHTCs for Aerospace Applications Initiated Over Thirty Years Ago

- Based on work performed by ManLabs Inc. in the 1960's and 1970's for the Air Force
- In the early 1990's Ames began investigating these materials for sharp leading edge applications.
  - Ground based research: initial materials development, arc-jet testing, computer modeling, etc.
  - SHARP-B1(1997) and SHARP-B2 (2000) ballistic flight experiments

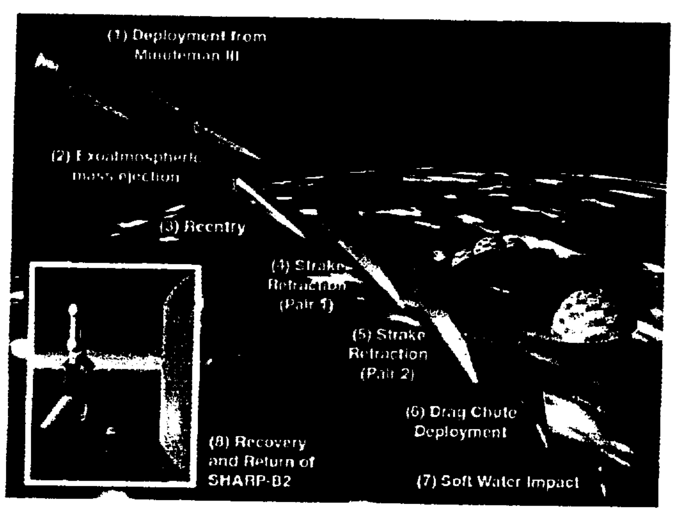
TPS

Diborides Have Very High Melting Temperatures

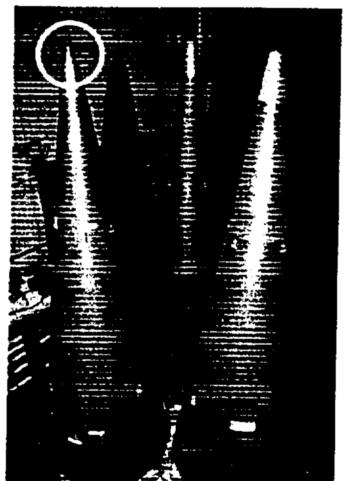




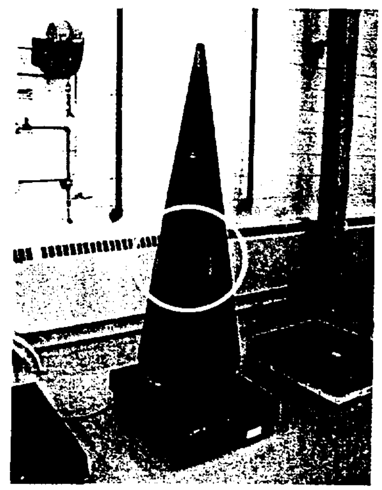
Missions Like SHARP-B2 Provide a Method to Evaluate Materials in a True Hypersonic Reentry Environments



Flight Hardware



SHARP-B1 May 21, 1997



SHARP-B2 Sept. 28, 2000

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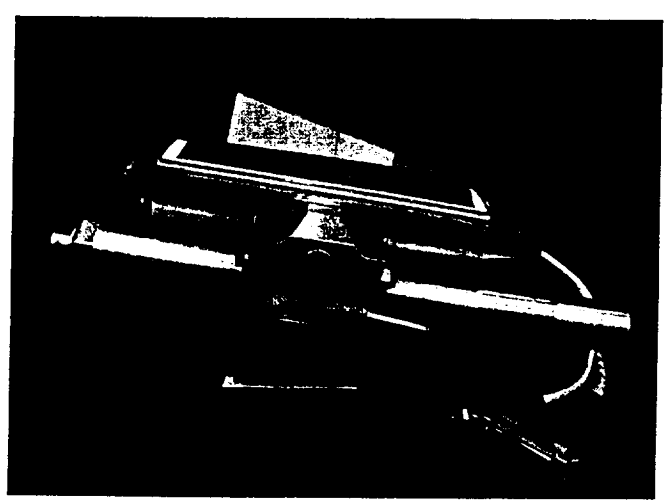
UHTC Strake Configuration was Chosen to Represent a Sharp Leading Edge Geometry



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Much UHTC Research and Development Has Focused on Three Compositions

Ames Research Center

- Compositions:
  - HfB_2/20% SiC
  - ZrB_2/20% SiC
  - ZrB_2/30% C/14% SiC
- Based on compositions investigated by ManLabs Inc.
- Base material is the diboride with SiC particles and/or C flakes
- Materials were hot pressed
- Recent materials have been processed using external vendors

TPS

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UHTC Material Properties

Ames Research Center

Property	HfB_2/SiC	ZrB_2/SiC	ZrB_2/C/SiC
Density (g/cc)	9.57	5.57	4.51
Strength (MPa) 21°C	356±97*	552±73*	135±10*
1400°C	137±15*	240±79*	101±9*
Modulus (GPa) 21°C	524±45	518±20	122±9
1400°C	178±22	280±33	100±11
Coefficient of Thermal Expansion ($x10^{-6}$/K) RT	5.9	7.6	5.8
Thermal Conductivity (W/mK)## RT	80	99	79

Source: Southern Research Institute and ManLabs.

* Flexural Strength

R. P. Tye and E. V. Clougherty, "The Thermal and Electrical Conductivities of Some Electrically Conducting Compounds." Proceedings of the Fifth Symposium on Thermophysical Properties, The American Society of Mechanical Engineers, Sept 30 – Oct 2 1970. Editor C. F. Bonilla, pp 396-401.

TPS

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Summary

- RCC used on shuttle limited to multi-use temperature of ~1650°C.
- Temperature limit of RCC requires use of blunt bodies.
- Significant improvements in performance and safety can be achieved using sharp leading edges.
- To achieve improvements materials will be subjected to significantly higher temperatures.
- Requires the development of new materials that can survive these extremely high temperatures.
- Diboride composites show potential for these applications.